Mass Balance of Multiyear Sea Ice in the Southern Beaufort Sea

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LONG-TERM GOALS

1) Determination of the net growth and melt of multiyear (MY) sea ice during its transit transit the southern Beaufort Sea
2) Identification of key regional processes in southern Beaufort Sea affecting MY ice recruitment
3) Improved predictability of the future states of the Arctic ice pack

OBJECTIVES

We have four main scientific objectives:

I) <u>Estimation of MY ice volume entrained into the Beaufort Sea from north of Canada</u>

The region north of the Canadian Archipelago contains some of the oldest and thickest ice in the Arctic and the amount of this ice imported into the Beaufort Sea has a significant effect on the overall MY ice budget of the Arctic.

II) <u>Estimation of rate of thinning of MY ice during transit through southern Beaufort Sea</u>

The thickness of MY ice at the end of its westward transit through the Beaufort Sea will have a critical impact on the volume of MY ice recruited from one year to the next and on navigability in the Beaufort and other marginal seas.

III) <u>Assessment of contribution of refreezing of meltwater to overall mass balance of MY ice</u>

Meltwater created through surface ablation can refreeze if it finds its way underneath the sea ice where the ocean will typically be at the colder freezing point of seawater. This can create ice lenses and false bottoms beneath the sea ice and make a positive, but poorly-understood, contribution to the mass balance

IV) <u>Assessment of the role MY ice dispersal in promoting ice loss</u>

We speculate that diminished MY ice in the Beaufort Sea may be a consequence of changes in drift patterns. Moreover, if net drift and divergence increase as MY ice extent decreases, this

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may represent a feedback process that will accelerate the Arctic's trajectory toward a seasonally ice free state.

APPROACH

Overview

To address the scientific objectives identified above, we employ a data fusion approach using a range of public-domain in-situ and remote sensing datasets. Table 1 lists the primary data sources to be used. To determine sources and sinks of MY ice, we use a simple model of MY ice circulation, which is shown in Figure 1. In this model, we consider the Beaufort Sea to consist of four zones defined by mean drift of sea ice in summer and winter, such that it takes approximately one year for MY ice to drift from one zone to the next. The existence of these zones is demonstrated by the trajectories of drifting buoys (*Hutchings and Rigor*, 2012) analysis of satellite data (*Maslanik et al.*, 2007; *Kwok and Cunningham*, 2010). Whether or not the Beaufort Sea is a sink for MY ice in a given year will ultimately depend on the amount of ice imported from zone 1 and how much of this is replenished from zone 4. However, the critical stage of this cycle is the transit through zone 2 where the greatest amount of thinning takes place and where we focus our research effort using in situ data.

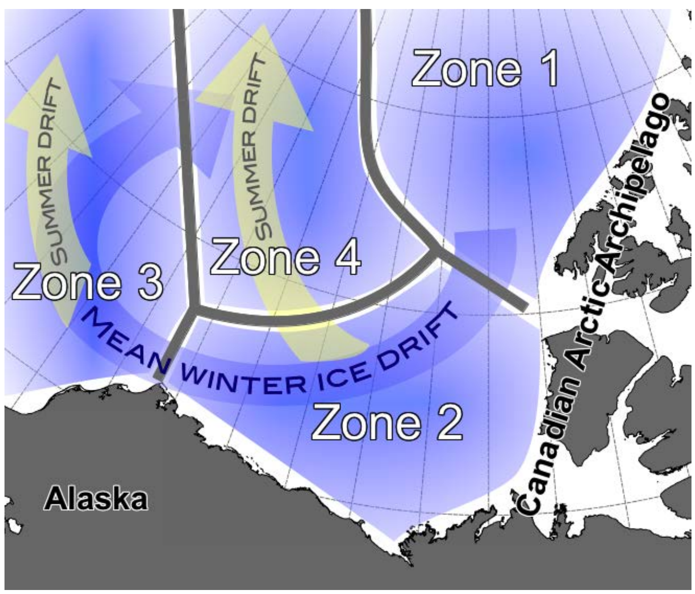

Figure 1: Schematic showing zones representing different stages in the transport of MY ice in the Beaufort Sea

Table 1: Summary of data and methods to be combine to study mass balance of Beaufort Sea sea ice

Property / process	***Instrument / method***	***Data source***
Thickness distribution	EM-bird	SIZONet[1], PAM-ARCMIP[2]
	Moored ice profiling sonars (IPS)	Beaufort Gyre Exploration Project (BGEP)
Drift and dispersal	GPS-tracked drifting buoys	IABP[3], SEDNA[4]
Growth and melt	Ice mass balance buoys (IMBs)	SIZONet[1], CRREL[5]
Age	Ice core analysis	SIZONet[1], *Louis S. St. Laurant* cruises
	Ship-based and airborne observations	SIZONet[1], *Healy/Louis S. St. Laurant* cruises

[1] Seasonal Ice Zone Observing Network
[2] Polar Airborne Measurements and Arctic Regional Climate Model Simulation Project
[3] International Arctic Buoy Program
[4] Sea ice Experiment - Dynamic Nature of the Arctic
[5] Cold Regions Research and Engineering Laboratory

MY ice volume entering Beaufort Sea (Objective I)

We can estimate the volume of MY ice entering the Beaufort Sea by assuming that the majority of it enters through the boundary between zones 1 and 2. Using data from individual buoys and interpolated ice velocity fields, we will calculate the areal flux of ice crossing this boundary. Ice thickness distributions derived from a combination of EM-bird flights and ice profiling sonar (IPS) data in this region (Figure 2) will allow us to calculate the total volume of ice crossing this line. The advantage of using in situ data for this analysis is the accuracy we will be able to obtain in assigning specific thickness measurements to MY ice. By using different means of identifying MY ice (e.g. such as in-flight sea ice observations, near-coincident SAR imagery, ice charts, passive microwave or bottom roughness statistics) we can quantify the uncertainty in MY ice volume between methods.

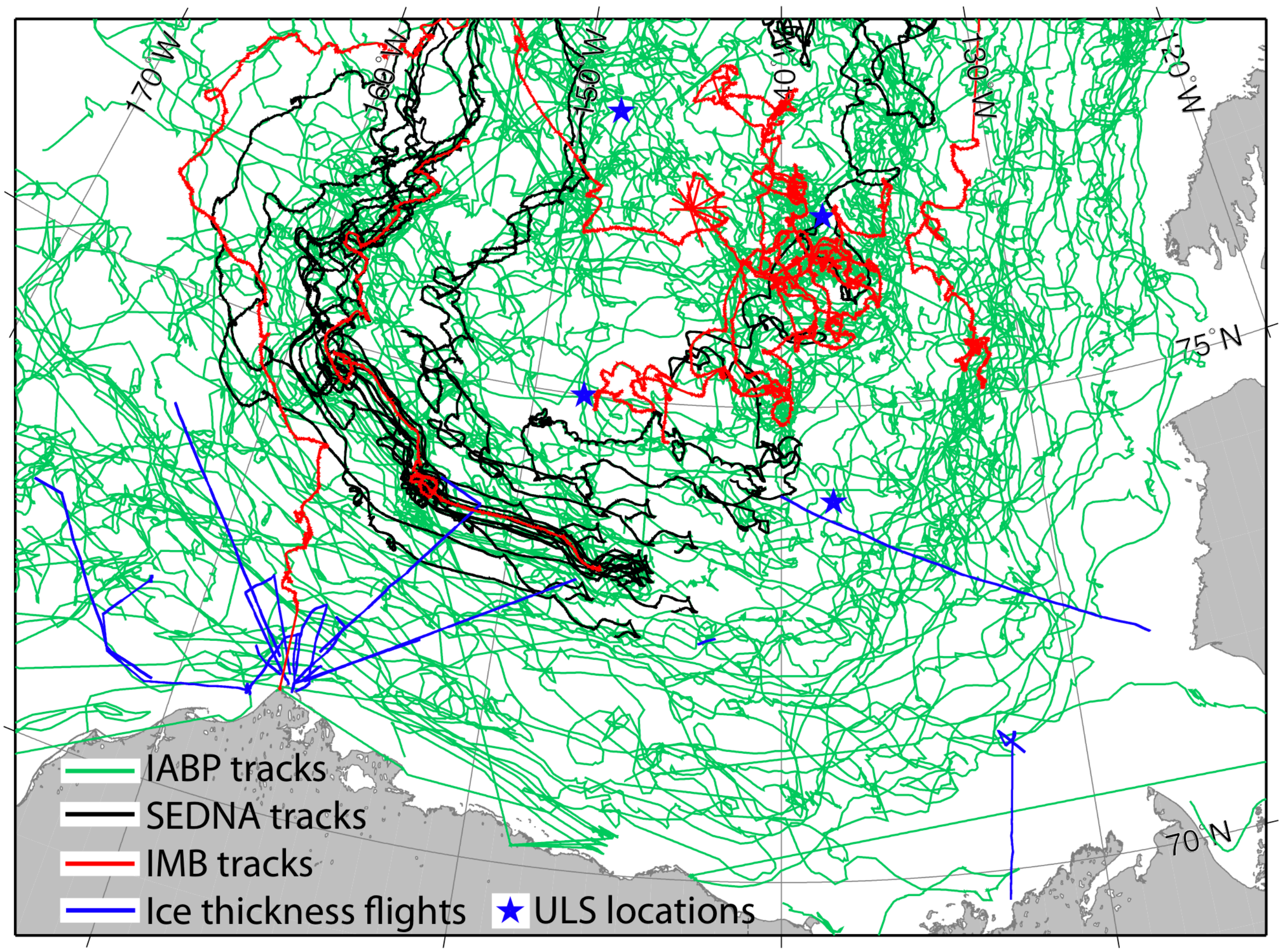

Figure 2: Map of the Beaufort Sea region illustrating the spatial coverage of buoy data during the period 2007-2010, together with the locations of EM-bird ice thickness flights and upward looking sonars (ULS)

Thinning of multiyear ice in southern Beaufort Sea (Objective II)

The in situ dataset we are assembling will provide multiple means of investigating the amount of thinning experienced by buoys transiting zone 2. First, we will estimate the total amount of thinning by comparing ice thickness distributions in the eastern and western Beaufort Sea from EM-bird and IPS data. Comparison of the modal thicknesses will allow us to examine the change in thickness of level MY ice while differences in the tails of the distributions will shed light on preferential melting of thick ridges. We will then compare these results with direct measurements of thinning from IMBs. These data will allow us to calculate top and bottom melt rates from MY floes in different parts of the Beaufort Sea, from which we can determine the amounts of thinning that can be attributed to atmospheric and oceanic heat fluxes. Identifying the oceanic contribution to thinning will be critical in understanding regional feedbacks between sea ice concentration and enhanced ocean heat fluxes as suggested by Shimada et al. (2006).

We will also study the loss of MY ice using non-mass balance buoys by analyzing drift and remote sensing data in the days and weeks prior to their termination. The abrupt termination of non-floating buoys with healthy battery levels during summer can be taken as a sign of complete melting of the floe in which they were drifting. As part of our analysis, we will seek all available metadata describing the type, thickness and size of floes in which buoys are deployed. By analyzing such occurrences in conjunction with remote sensing products, such as sea ice concentration and sea surface temperature, we will improve our understanding of the conditions in which multiyear floes melt completely.

Mass balance contribution and uncertainty from refreezing surface melt (Objective III)

In addition to studying growth and ablation rates with the IMB data, we also propose to use the data to examine the contribution of refreezing of melt water to the overall mass balance of MY ice and the uncertainty this introduces in the mass balance measurements. By comparing data from the upper and lower acoustic sounders (Figure 3), we will identify occasions when surface ablation was taking place at the same time as bottom growth. We will then examine temperature profiles in and below the ice to look for water temperatures of 0 °C, which will be indicative of the presence of freshwater below the ice. We will support this analysis by looking for refrozen melt water in ice cores that have been collected in conjunction with the ice thickness flights.

Although refreezing of meltwater may be a zero-sum component of the mass balance, it has the potential to be a considerable source of uncertainty if it leads to the formation of false bottoms. False bottoms are created when a layer of ice forms at the interface between the fresh water and seawater leaving a pocket of unfrozen freshwater above. We expect that in these cases, the acoustic sounder would detect the false bottom, thereby overestimating the total thickness of the sea ice. However, the presence of false bottoms should be evident in the temperature profiles if the temperatures above the depth indicated by the acoustic sounder are close to 0 °C.

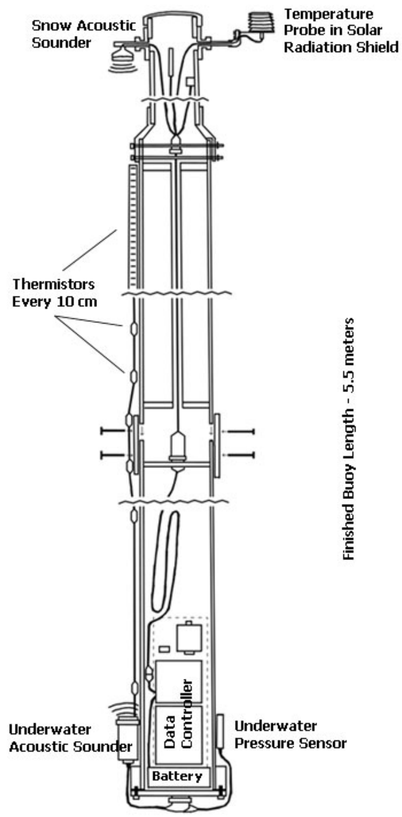

Figure 3: Sketch of seasonal IMB, from http://imb.crrel.usace.army.mil/

Effect of ice dynamics in enhancing multiyear ice loss (Objective IV)

In order to better understand the processes affecting the concentration of MY ice in the Beaufort Sea, we will examine changes in thickness distribution in the context of data from high-resolution drift data from the SEDNA project and an NSF AON project (Hutchings and Rigor, ARC 1023662, 01/01/2011-12/31/2014). Combining drift data from closely-spaced buoys with synthetic aperture radar (SAR) data, SEDNA has been able to capture meso-scale deformation of sea ice in the Beaufort Sea [Hutchings *et al.*, 2011].

Divergence of the ice pack will be estimated, at the scale of the buoy spacing, throughout the Beaufort Sea by tracking buoy triads and using Green's Theorem's to calculate strain-rate as demonstrated by Hutchings and Hibler [2008] and Hutchings et al [submitted]. Sub-daily divergence monitoring is required as lower resolution products (such as those derived from satellite data) under-estimate ice growth in leads [*Hutchings et al.*, 2011]. Divergence of sea ice allows new ice growth in leads, which affects the rheological properties of the ice pack and in turn affects sea ice dynamics potentially leading to increased divergence. If the rate of MY ice divergence is increasing in the Beaufort Sea, the increased fraction of thin FY ice would enhance summer melt rates, setting up a regional feedback process consistent with that suggested by Shimada *et al*.[2006]. The comprehensive dataset of in situ observations from the Beaufort Sea offers a unique opportunity to identify and quantify regional

feedbacks between ice dynamics and mass balance, which will be critical in the predictability of ice conditions of timescales of 5-10 years.

Project personnel

Andrew Mahoney UAF	PI, project coordination, assimilation and analysis of thickness, drift and mass balance data
Hajo Eicken UAF	Co PI, analysis of mass balance and ice core data
Jenny Hutchings UAF	Co PI, drift and mesoscale deformation analysis
Christian Haas Univ. Alberta, Canada	Collaborator, analysis of ice thickness data and contribution of data from surveys in the high Canadian Arctic

WORK COMPLETED

The project is still in its early stages as our period of performance began on July 1, 2012. In the three months since, we have begun compiling data from the sources listed above in Table 1. The data acquired to date are listed in Table 2

Table 2: Datasets compiled to date

Geophysical data type	*Source*	*Time period acquired*
Buoy tracks	IABP	12 hrly position data 1978-2012
Ice thickness	SIZONet	April campaigns 2009-12
Ice thickness	BGEP	2003-2010
Aerial photography	NASA IceBridge	Arctic sea ice flights 2011-12
Sea ice concentratio	NSIDC	1978-present

In addition to acquiring the data files, we have also been assembling related metadata. In the case of the IABP data, we have started creating a database containing information on each buoy including the buoy's owner, deployment and failure dates and what sensors are installed. We will use this information together with buoy tracks and ice concentration to identify buoys that are likely to failed to complete melting of the multiyear floe in which they were deployed. We have planned a meeting of all project participants in Fairbanks in late October to plan initial analysis steps and acquisition of additional datasets.

RESULTS

No results yet to report

IMPACT/APPLICATIONS

We anticipate our future results will improve understanding of the fate of multiyear sea ice in an increasingly seasonal ice pack and lead to reduced uncertainty in sea ice forecasting.

RELATED PROJECTS

PI Mahoney is involved in the NASA-funded The Marginal Ice Zone Observations and Processes EXperiment (MIZOPEX; http://ccar.colorado.edu/mizopex/). This project will use multiple unmanned aircraft to obtain a variety of data over the marginal zone in the Beaufort Sea. Mahoney's involvement focusses on the analysis of sea ice data.

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